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TECHNICAL NOTE

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IN-FLIGHT MEASUREMENT OF THE TIME REQUIRED FOR A PILOT TO RESPOND TO AN AIRCRAFT DISTURBANCE

By Helmut A. Kuehnel

Langley Research Center
Langley Field, Va.

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SUMMARY

Measurements of the time required by the human pilot to detect and initiate a correction for an airplane disturbance have been made in flight. The pilot's task was to correct for an applied lateral or longitudinal airplane disturbance as rapidly as possible. The time lapse from the start of a disturbance to the start of a pilot correction was measured for three pilots performing a total of 51 data runs.

The results of this investigation indicate that the average pilot's reaction time for moderate to large lateral airplane disturbances is 0.23 second and that the average reaction time for moderate longitudinal airplane disturbances is 0.33 second.

INTRODUCTION

The National Aeronautics and Space Administration is presently conducting a program aimed at documenting the human pilot's dynamic-response characteristics for tasks dealing with the control and stabilization of aircraft. As part of this overall program, the pilot's reaction time, or the time for the pilot to compute and initiate a correction for an aircraft disturbance, has been measured under visual flight conditions in a jet-powered airplane. Pilot reaction time has a profound effect on the degree of divergence of an aircraft in situations where pilot control is required to correct an airplane upset, such as an automatic control system failure or external aircraft disturbance due to a sharp gust. The present data should be considered as minimum pilot reaction times obtained with an extremely attentive pilot which may not necessarily be the case in an operational situation.

Measurements of the human operator's reaction time have been made in the past and are reported in the various physiological journals. However, most of these experiments have been conducted under controlled laboratory conditions. It is desirable for the present purpose of determining the pilot's reaction time in flight, that the reaction time be measured in the rather complex environment of actual flight, where the task requires a response in the correct direction and also a monitoring of the magnitude of the response in order to be successful in correcting for an aircraft disturbance. Some measurements of pilot reaction time are reported as parts of more complete works in references 1, 2, and 3 but again these do not include the presence of possible pilot apprehension about causing structural damage to his airplane in the event of an indiscreet corrective control movement.

The tests were conducted in a jet-trainer airplane which was modified to allow the safety pilot to disturb the airplane without moving the L
subject pilot's control stick. The subject pilot's task was to correct 7
for the applied disturbance as rapidly as possible. Pilot stimuli for 3
these tests result from an airplane upset of varied severity ranging 8
from barely perceptible to the pilot in the presence of other random airplane motions to large and readily detectable disturbances in both pitch and roll.

SYMBOLS

a_n normal acceleration, g units

b wing span, ft

c wing chord, ft

$C_{m_{\delta e}}$ rate of change of pitching-moment coefficient with elevator angle, per radian

$C_{l_{\delta a}}$ rate of change of rolling-moment coefficient with aileron angle, per radian

F_a subject pilots' aileron stick force, lb

F_e subject pilots' elevator stick force, lb

I_X moment of inertia about X-axis, slug-ft^2

I_Y moment of inertia about Y-axis, slug-ft^2

p rolling velocity, radians/sec

$\dot{p}$ rolling acceleration, radians/sec^2

q pitching velocity, radians/sec

$\dot{q}$ pitching acceleration, radians/sec^2

$\bar{q}$ dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft

r yawing velocity, radians/sec

S wing area, sq ft

θ pitch attitude, deg

τ subject pilot's total reaction time, sec

ϕ roll attitude, deg

$\delta_{a,i}$ disturbing control stick deflection, calibrated in terms of total aileron deflection, deg

δ_a total aileron surface deflection, deg

$\delta_{e,i}$ disturbing control stick deflection, calibrated in terms of elevator deflection, deg

δ_e elevator surface deflection, deg

ρ air density, slug/cu ft

V true airspeed

x,y coordinate axes

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APPARATUS AND TEST AIRPLANE

The test vehicle was a modified two-place jet trainer airplane. Modifications to the basic airplane consisted primarily of removing the existing dual controls from the rear cockpit and substituting a completely independent research control system which gave the necessary isolation between an airplane disturbance and a pilot response. The rear cockpit controls used by the subject pilot were irreversible hydraulic systems with artificial feel and were engaged in flight by the front or safety pilot after the airplane had been trimmed at the particular flight conditions for the test. Engagement of the subject pilots' control system makes the safety pilot's normal control system inoperative.

However, a side-located controller with spring centering has been mounted in the front cockpit and was differentially connected to the subject pilot's controls. This side-located controller allowed the safety pilot to fly the airplane when the research control system was engaged and was the means by which discrete airplane disturbances have been applied for this experiment. A pictorial sketch of the control-system linkage and interconnection of the side-located controller with the subject pilot's controls is presented in figure 1, and a simplified sketch of the longitudinal control system is shown in figure 2. A simple spring feel system was incorporated in the subject pilots' controls and gave the stick force-deflection characteristics as shown on figure 3. The input links of the differential shown in figure 1 (or the ends of the summing link shown in fig. 2) are connected to the subject pilot's control stick and the front-cockpit side-located controller, and the output link is connected to the hydraulic servo valve of the research control system. High-frequency shaker devices were mounted in close proximity to the hydraulic servo valve in order to reduce the friction at the valve; thus, all motion of either input link is fed directly to the servo valve and not to the other input link. This is a necessary requirement of the control system so that the subject pilot will receive no advanced cues of an impending airplane disturbance through his control stick. Arrows on figure 1 indicate the linkage motion for up-elevator deflection and left aileron deflection. In-flight adjustable stops are provided on the side-located controller to facilitate covering a range of disturbance amplitudes in a single flight. The subject pilot's control stick could command $\pm 4^{\circ}$ of elevator angle and 16° of total aileron angle which was adequate control power for all flight conditions except possibly landing and take-off or extreme low-speed maneuvers that may require full-up elevator control.

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INSTRUMENTATION

Instrumentation consisted of standard NASA film recording instruments to measure the following airplane quantities: airspeed, pressure altitude, pitch rate, roll rate, yaw rate, pitch attitude, roll attitude, heading, and the three linear accelerations, normal, transverse, and longitudinal. Elevator, aileron, rudder, and front-cockpit side stick position were recorded. The force applied to the rear-cockpit control stick was also recorded. A standard NASA 10-channel telemeter was used to record the subject pilot's stick position and to duplicate the recordings of angular velocity, normal acceleration, and transverse acceleration obtained with on-board film recording equipment. The telemeter also transmitted additional information needed for other phases of this program.

TESTS

Tests were started with the subject pilot flying the airplane in trimmed level flight at an altitude of 20,000 feet and an airspeed of 180 knots. The subject pilot was aware that the airplane would be disturbed, but he did not know exactly when the disturbance would occur nor its direction or magnitude. The airplane disturbance is applied by the safety pilot by rapidly deflecting the side-located controller against a mechanical stop. If the subject pilot does not apply corrective control, the airplane response to discrete elevator and aileron disturbances as used in this study would be as shown in figures 4 and 5. Figure 4(a) shows the airplane response to a pulse elevator deflection, and figure 4(b) shows the airplane response to a step elevator deflection. Figures 5(a) and 5(b) show similar airplane response to left aileron pulse and step control deflections. The subject pilots' task during the reaction time experiment was to return the airplane to straight and level flight as rapidly as possible following an airplane disturbance of the types shown in figures 4 and 5. Figure 6 shows typical time-history representations of the pilot response data and resulting airplane motions obtained in this experiment when the pilot corrects for the applied airplane disturbances. Three experienced research test pilots participated in this program and made a total of 51 data runs.

RESULTS AND DISCUSSION

Pilot-reaction-time data were obtained from flight records similar to those shown in figure 6. The quantities plotted on figure 6 are the control surface deflection used to disturb the airplane $\delta_{e,i}$ or $\delta_{a,i}$, the subject pilot's stick force in response to the disturbance F_e or F_a, resulting control-surface deflection δ_e or δ_a which is the sum of the disturbance shown in the top trace and the pilot's response resulting from the stick force in the second trace. The resulting airplane attitude θ or ϕ and angular velocity q or p are also shown in figure 6 along with normal acceleration a_n for the case of a longitudinal airplane disturbance. The subject pilots' reaction time is the time interval between the start of an airplane disturbance as indicated by the control-surface deflection and the start of a pilot response as indicated by his stick force record. Pilot reaction time as used here includes the time required to recognize a disturbance and compute a course of action and also a neuromuscular time required to start the pilot's arm motion in order to deflect the control stick. Pilot reaction time was measured from the flight records and tabulated along with the magnitude of the airplane disturbance that led to each reaction. The magnitude of the disturbance was measured from the flight data as control-surface deflection and these quantities were then converted to their resulting angular accelerations at the time immediately following the control deflection by the following expressions:

$$\dot{p} = \left(\frac{bS\bar{q}}{I_X} C_{l_{\delta a}}\right)\delta_a$$

$$\dot{q} = \left(\frac{cS\bar{q}}{I_Y} C_{m_{\delta e}}\right)\delta_e$$

Coefficients, airplane dimensions, and inertia characteristics used in these expressions are listed in table I for the flight conditions used in this study.

It was observed from the data that there was no consistent dependence of reaction time on the magnitude of a lateral airplane disturbance for the range of rolling acceleration investigated in this study which was 0.5 to 1.7 radians/sec^2. It was, however, observed that the pilots' reaction time for a longitudinal disturbance was dependent on the magnitude of the disturbance in the range of pitch acceleration of 0.02 to 0.20 radians/sec^2. Measured reaction time of the three pilots that participated in this experiment is tabulated below for a single range of lateral airplane disturbances and three ranges of longitudinal airplane disturbances.

Pilot	Disturbance amplitude, sec, for -			
	Rolling acceleration disturbance $\dot{p}$ of 0.5 to 1.7 radians/sec^2	Pitch acceleration disturbance $\dot{q}$ of -		
		0.02 to 0.04 radians/sec^2	0.04 to 0.2 radians/sec^2	Above 0.2 radians/sec^2
A	0.16 to 0.30	0.4 to 0.8	0.25 to 0.48	0.2 to 0.24
B	0.22 to 0.25	No response	0.2 to 0.32	0.2 to 0.24
C	0.20 to 0.30	0.4 to 0.6	0.22 to 0.45	0.2 to 0.24

The three ranges of longitudinal disturbances correspond to a region of very small disturbances ($\dot{q}$ = 0.02 to 0.04 radians/sec^2) characterized by uncertain pilot reactions and resulting long and widely scattered reaction time measurements, a region of moderate airplane disturbances

($\dot{q}$ = 0.04 to 0.2 radians/sec^2) with shorter and more consistent pilot reaction times, and lastly a region of large airplane disturbances ($\dot{q}$ greater than 0.2 radian/sec^2) with short and consistent pilot reaction times. These three regions are based partly on pilot comments during the experimental runs and partly on the amount of scatter in the pilots' reaction-time measurements. The magnitude of lateral disturbances was not reduced to the low values used in the longitudinal tests and therefore a definite dependence of pilot reaction time on lateral-disturbance amplitude could not be established. It is felt, however, that the range of lateral-disturbance amplitudes where the pilots' response is uncertain would be of a higher magnitude laterally than it is longitudinally.

A composite plot of the variation of pilot reaction time with the magnitude of an airplane disturbance is shown in figure 7 for the longitudinal mode. Here again it is evident that there is a greater variability in reaction time for small airplane disturbances and that the reaction time becomes fairly constant at larger values of airplane disturbance amplitude. One explanation for the measured scatter in pilot reaction time for the smaller airplane disturbances is that the disturbances in some cases were barely perceptible and the pilot would correct very slowly as if he were correcting the airplane trim instead of correcting for a discrete disturbance. Consequently, it was difficult to determine the exact time of pilot response from these records. Time-history plots to show the pilots' response over a range of longitudinal disturbance amplitudes is presented in figure 8. Figure 8 shows the disturbing control deflection $\delta_{e,i}$, subject pilot's stick force F_e, resultant elevator angle δ_e (disturbance plus pilot correction), airplane pitch attitude θ, pitching velocity q, and normal acceleration a_n for a range of initial angular acceleration due to the elevator disturbance of 0.227 radian/sec^2 to 0.018 radian/sec^2.

These data show that, during the pilot's reaction-time interval, the airplane diverges very little from its trim attitude, and that a control system failure or other airplane disturbance that is within the pilot's capability to correct should pose no serious flight safety problem if the pilot is as alert as he was in these tests. It is recognized, however, that this degree of alertness or attentiveness on the part of the pilot is impractical on long duration flights and the reaction times measured here should be considered as absolute minimum values.

CONCLUSIONS

In-flight measurements of the time required for a pilot to initiate a correction for rapidly applied pitching and rolling disturbances of various amplitudes have been conducted. The results of this investigation indicate the following conclusions:

1. The average values of pilot reaction time is about 0.23 second in response to moderate to large lateral disturbances and about 0.33 second in response to moderate longitudinal disturbances.

2. Pilot reaction time was found to be longer and less consistent in response to small longitudinal disturbances. Pilot reaction time in response to large longitudinal disturbances (that would result in an initial angular acceleration of about 0.23 radian/sec^2) are fairly consistent and range in magnitude from a minimum of 0.2 second to about 0.24 second.

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Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., November 3, 1959.

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2. Searle, Lloyd V., and Taylor, Franklin V.: Studies of Tracking Behavior. I. Rate and Time Characteristics of Simple Corrective Movements. Jour. of Experimental Psychology, vol. 38, no. 5, Oct. 1948, pp. 615-631.

3. Taylor, F. L.: Certain Characteristics of the Human Servo. Electrical Engineering, vol. 68, Mar. 1949, p. 235.

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TABLE I

AIRPLANE CHARACTERISTICS ASSUMED IN COMPUTING ANGULAR ACCELERATION IMMEDIATELY AFTER A CONTROL INPUT

b, ft	37.54
c, ft	6.72
S, sq ft	234.8
I_X, slug-ft^2	8,364
I_Y, slug-ft^2	20,274
$C_{l_{\delta a}}$, per radian	-0.12
$C_{m_{\delta e}}$, per radian	-0.82
$\bar{q}$, lb/sq ft	109.3

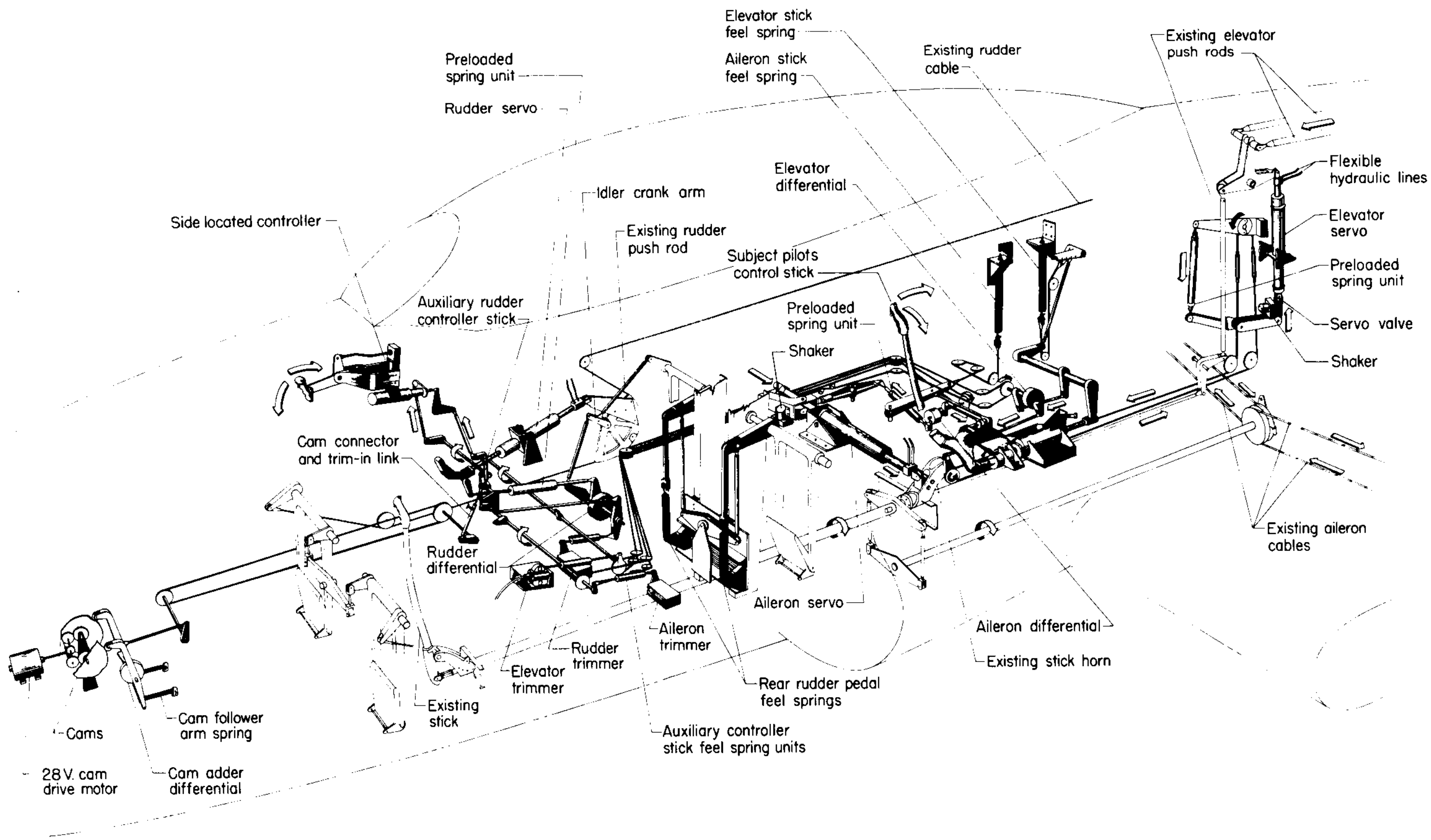

Figure 1.- Pictorial sketch of the research control system and tie-in with the normal airplane system.

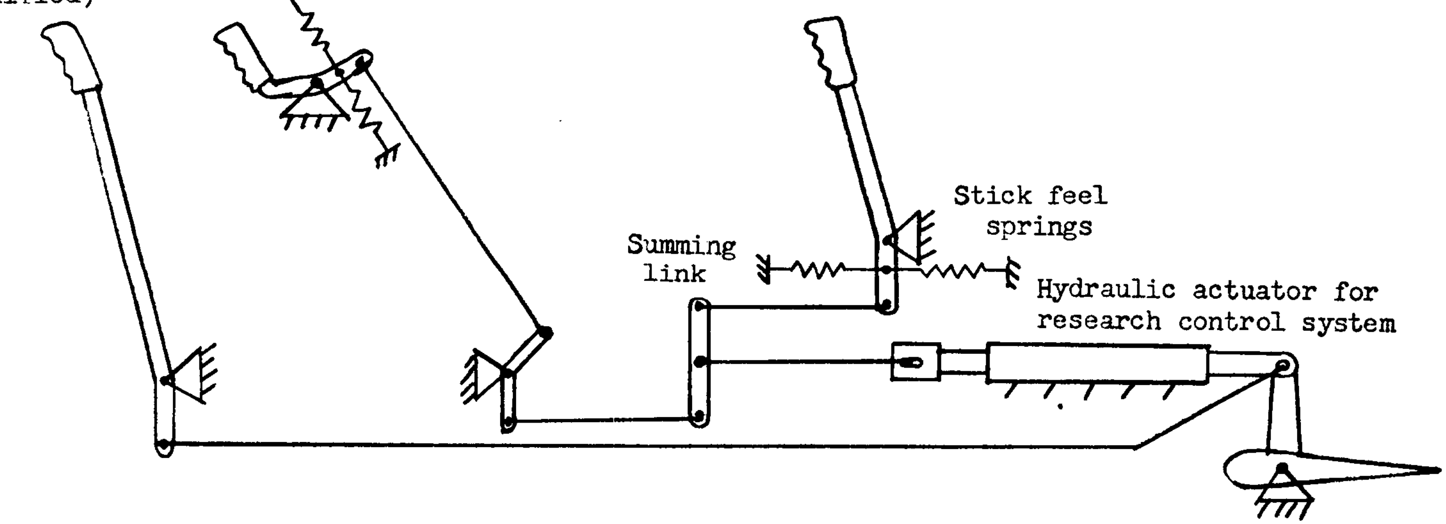

Figure 2.- Simplified sketch of the research pitch control system and tie-in with the normal airplane control system.

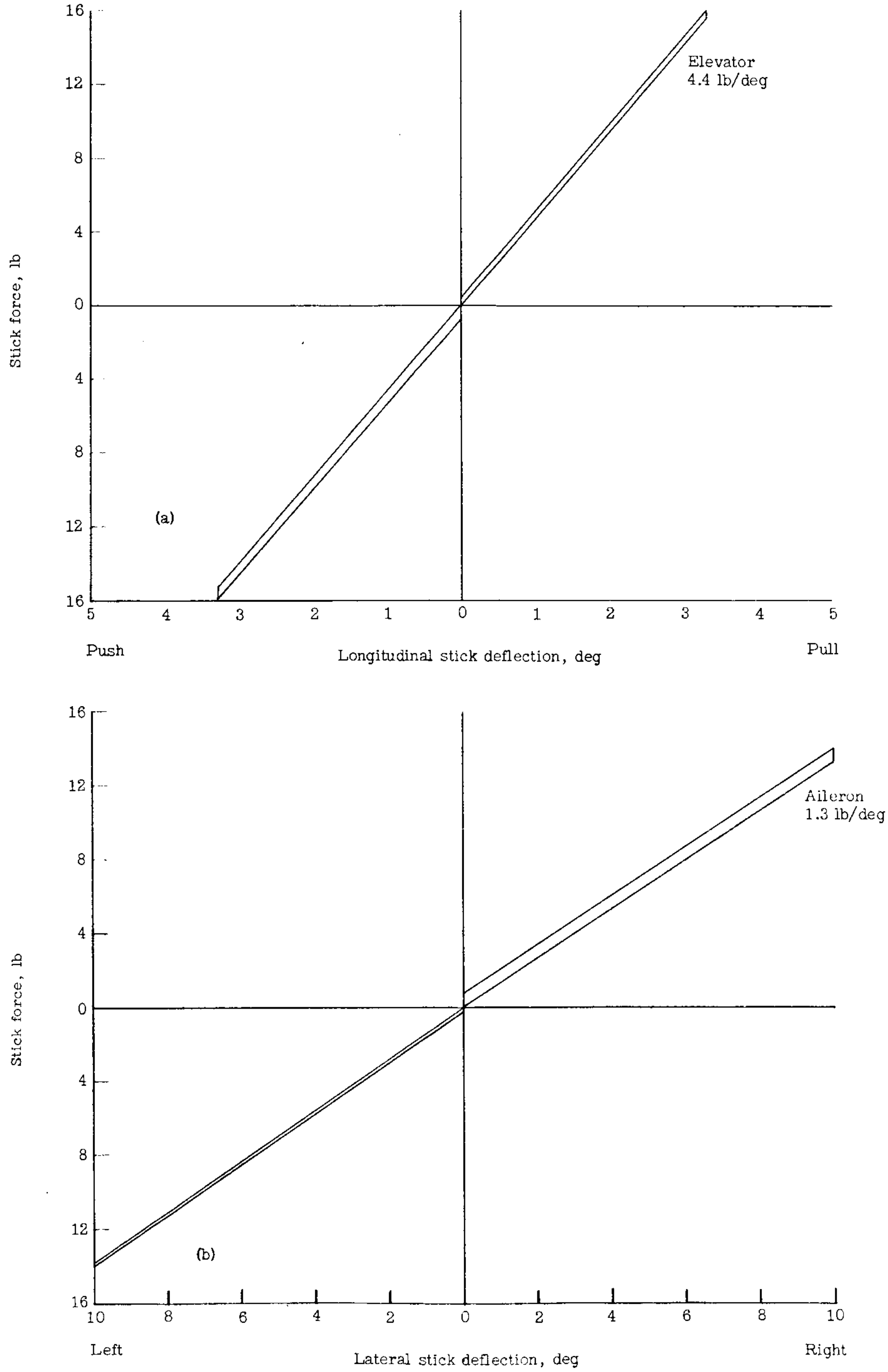

Figure 3.- Variation of the subject pilot's control stick force with stick deflection.

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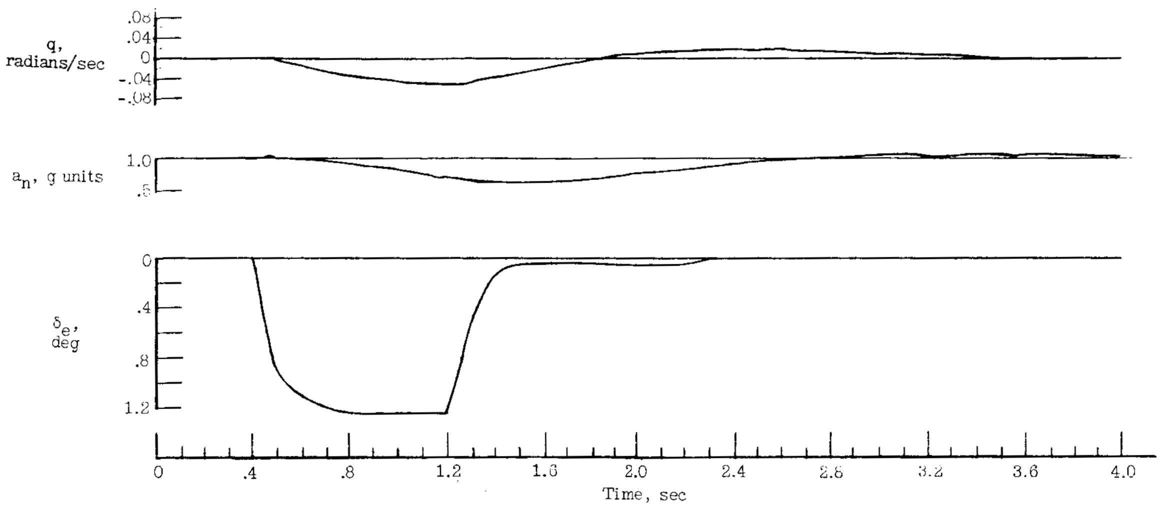
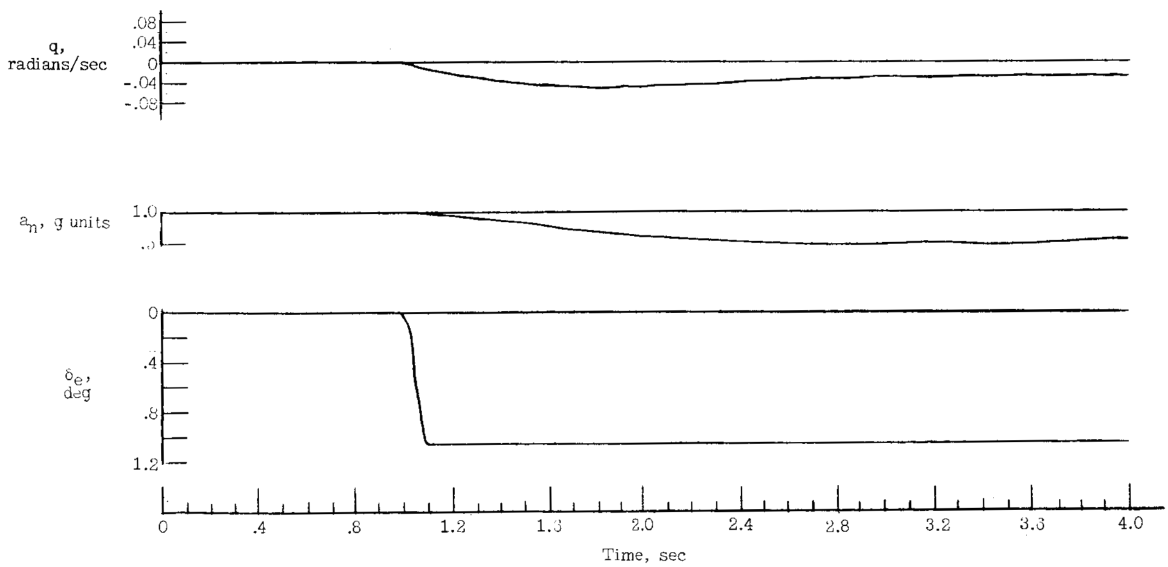
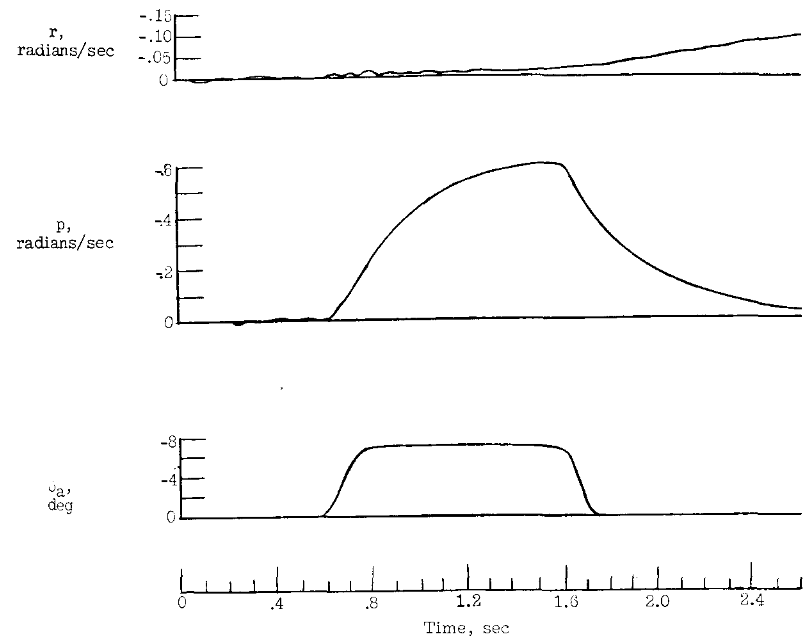


(a) Pulse disturbance.

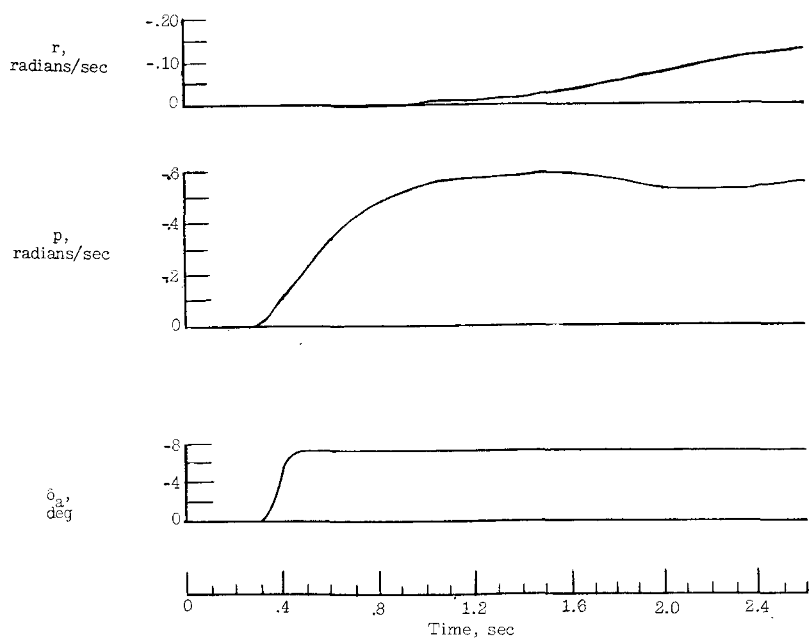


(b) Step disturbance.

Figure 4.- Airplane response to longitudinal control disturbance.

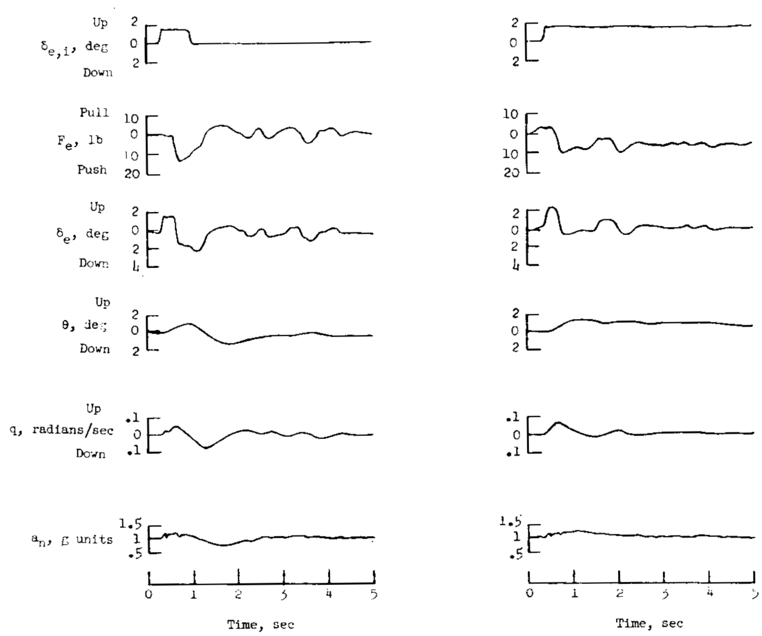


(a) Pulse disturbance.

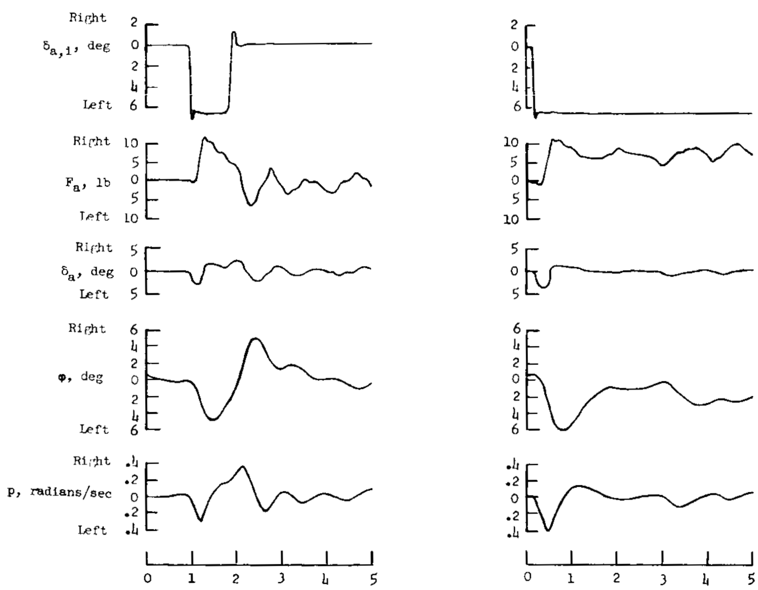


(b) Step disturbance.

Figure 5.- Airplane response to lateral control disturbance.



(a) Pulse elevator disturbance. (b) Step elevator disturbance.



(c) Pulse aileron disturbance. (d) Step aileron disturbance.

Figure 6.- Time history of the airplane motions during a pilot response to rapidly applied airplane upsetting disturbances.

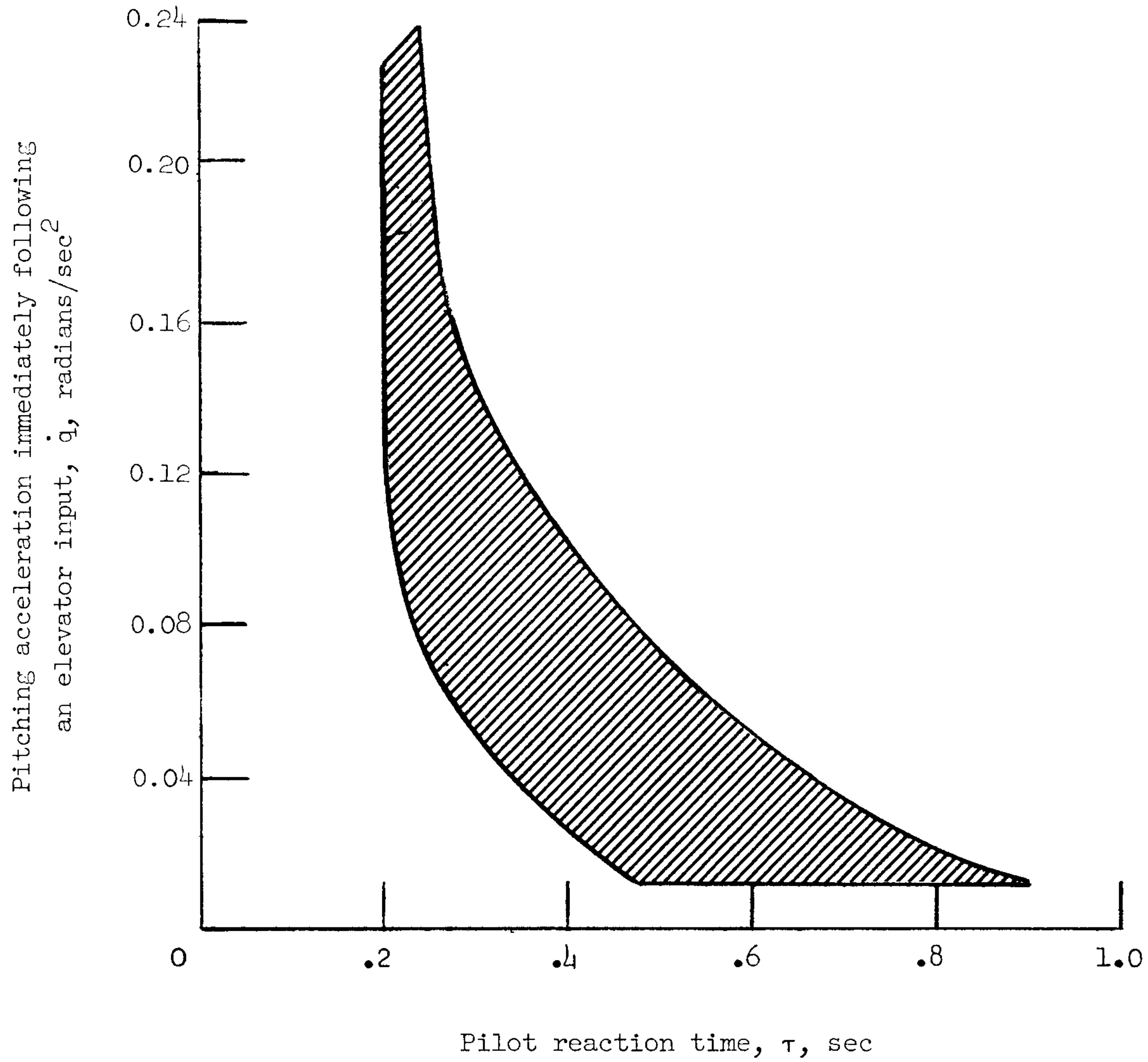
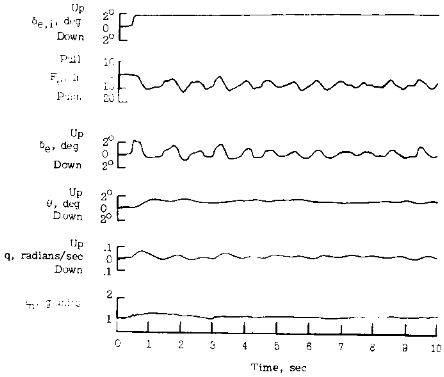
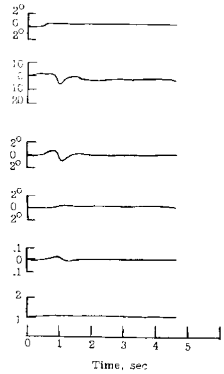


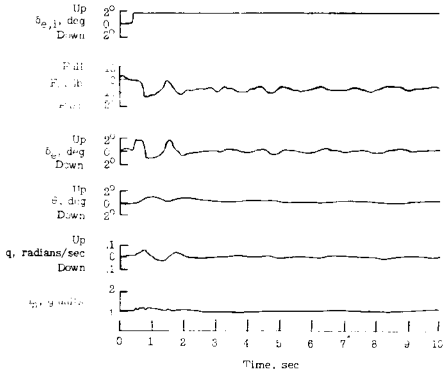
Figure 7.- Measured variation and scatter of pilot reaction time over a range of pitching acceleration.



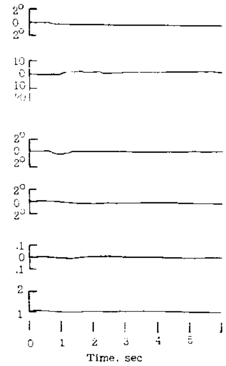
(a) $\dot{q} = 0.227$ radian/sec^2.



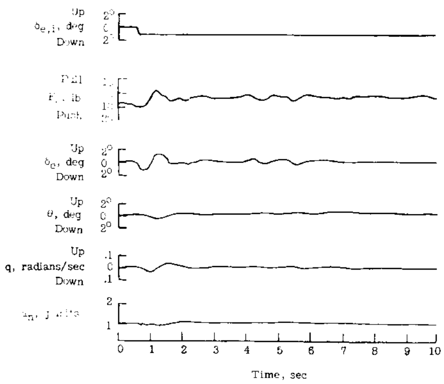
(d) $\dot{q} = 0.72$ radian/sec^2.



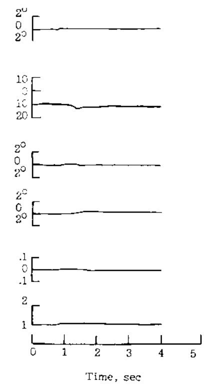
(b) $\dot{q} = 0.204$ radian/sec^2.



(e) $\dot{q} = 0.036$ radian/sec^2.



(c) $\dot{q} = 0.144$ radian/sec^2.



(f) $\dot{q} = 0.018$ radian/sec^2.

Figure 8.- Time history of pilots' response to step elevator disturbances over a range of disturbance amplitudes.